II. "On the Limit of Visibility of the different Rays of the Spectrum. Preliminary Note." By Captain W. de W. Abney, C.B., R.E., D.C.L., F.R.S. Received April 29, 1891.

In certain photometric experiments it became necessary to find the limit of visibility of the different parts of the spectrum, and also to ascertain what ratio this limit would bear to some fixed luminosity. It should be borne in mind that this question is totally different from acuteness of vision, which some have confounded with it. The two are independent one of the other, and can scarcely be compared.

The instrument used in these experiments was similar to that described in the note on the examination of a case of Tobacco Scotoma, &c., but the dimensions were modified:—A square tube, 3 feet long, had an aperture of 2 inches cut in its side at 2 feet 6 inches from one end, and covered over with ground glass. Within the tube, and close to the ground glass, was a mirror, which reflected the light coming through the ground glass on to the end of the tube, and if the ground glass was illuminated by any light the reflection illuminated a card placed at the end of the tube. The illumination of the card could be viewed through a circular hole at the other end of the tube, in which was fixed a smaller tube, fitting closely into the eye. If a colour patch from the spectrum was thrown on to the ground glass, evidently the card at the end of the tube would be illuminated by the colour used, and its disappearance could be effected by means of rotating sectors closing and opening at will, placed in front of the patch. This simple piece of apparatus answered its purpose most effectively.

The first point to ascertain was the ratio of illumination of the card to that of the patch thrown on the ground glass. The following arrangement was made to effect this. The end of the tube, against which the card was placed, was removed, and a card with a square hole, of $\frac{3}{4}$-inch side, was inserted instead. This was covered on the side away from the tube with a piece of Saxe paper, and when viewed from the outside, and when illuminated by the light from the ground glass, showed as a square patch of light. Outside of this, and of double the width, but of the same height, a mask of black paper, with an oblong aperture, was placed so that the illuminated square occupied one-half of the oblong, and the other half showed no white paper. An amyl acetate lamp (0·8 of standard candle), placed at a fixed distance from this oblong, and in a line with the axis of the tube, illuminated both squares; but a rod placed in proper position cast a shadow on the translucent square, allowing only the opaque white half to be illuminated. When the sectors above alluded to were placed in front of the lamp, the two

brightnesses could be equalised, and the intensities of the light transmitted passing through the paper estimated.

Now there is a ray very near D in the spectrum, whose colour is very closely, if not quite, identical with the colour of the light emitted by the burning amyl acetate, and for making the measures this ray was used. When the measure had been made, the screen, with the square aperture, was placed in the position of the ground glass, and the amyl acetate lamp placed on the side of the screen, away from the colour patch, and the rod placed in position to cast the shadow necessary. The rotating sectors were then placed between the spectrum and the screen, and the light reduced so that the illumination of the translucent and opaque white square, *viewed from the side of the lamp*, was equalised. Knowing the distance of the lamp in the two cases, and the aperture of the sectors, the relative illumination of the two surfaces was ascertained. For convenience, the aperture of the ground glass was limited by means of a diaphragm, or by placing a diaphragm in front of the first prism.

Two sets of measures showed that if the illumination of the ground glass be represented by 1, the illumination of the card at the end of the tube was $\frac{1}{700}$; that is, any light falling on the ground glass was diminished to that extent.

The actual measures were $\frac{1}{690}$ and $\frac{1}{714}$, but we may take $\frac{1}{700}$ as sufficiently close to the truth.

The colour-patch apparatus to which reference is made is described in the Bakerian Lecture, 1886 (Abney and Festing, "Colour Photometry"). The only addition to it that was made was to use an adjustable slit to move through the spectrum. There was thus a treble means of altering the intensity of the light, viz., by altering the aperture of the slit of the collimator, by altering that of the slit of the slide, which was shifted at will into different parts of the spectrum, and by the rotating sectors placed in front of the spectrum. The mode of proceeding to measure the luminosity at which light disappeared was as follows:—The dullest part of that portion of the spectrum which it was desired to extinguish was allowed to pass through the slit in the spectrum, and a patch was formed on the ground glass, which, it may be remarked, had a tube fitted over it, to prevent any chance of extraneous light reaching it. The card at the end of the square box was viewed, and the slits closed till all trace of light disappeared. (It may be as well to call to mind what is well known, that faint light of all colours appears as white.) In some sets of experiments the sectors were set at fixed angles, and rotated in front of the patch, and the slit in the spectrum moved from a position in which faint light appeared to one in which it just disappeared, the position in the spectrum being noted by the scale at the back of the moving slide carrying the slit. In other cases the slit

was placed at different positions in the spectrum, and the rotating sectors closed till all light had vanished, when the aperture was noted. The first plan is the more convenient of the two, and gives very accurate results; though in some positions of the spectrum the second method must be adopted, since the graphic curve formed from the readings becomes almost a horizontal straight line at one portion of the spectrum. As will be seen from the table, it is quite evident that no one aperture of the slit of the collimator and of that in the slide would suffice to give the entire range of disappearance of the spectrum, and that at least three settings are necessary. At each change the D light falling on the ground glass was measured, and the necessary factors to make the readings on one scale were derived from these measurements.

Four sets of measures throughout the spectrum were made on different days. No one differed to any appreciable extent from the other. A mean of the four has been taken as representing the truth, and the measures given in the first table are those of that which most nearly approaches this mean. It may be stated that very rarely did one curve differ more than 4 per cent. from another at any portion of the spectrum. The readings were taken when the eye had rested in darkness some time, and were often repeated a considerable number of times, the first parts measured being remeasured last. That the eye was equally sensitive throughout the time may be judged from the fact that the two sets of readings scarcely ever differed. The process of making these measures of extinction is very fatiguing, and probably rather detrimental to the eyesight; owing to the strain on the eyes, one set of readings is usually as much as can be properly carried out on any one day, if accurate results are to be looked for.

It is now three years ago since I began this research, and, after trying various plans, I have come to the conclusion that the method now described is the most easy, as it is the most simple.

There is one point in the method which might be open to criticism, and that is that the cutting off the light by rotating sectors might cause some error in the results. This criticism, I may say, I raised in my own mind at its very commencement, and found that it was unnecessary. Polarising the light entering the slit of the collimator, and then dimming it by means of a Nicol's prism placed in front of the colour patch, proved an unsatisfactory method for answering the criticism, as in no case could a total disappearance of a bright light be brought about; but by diminishing the area of the colour patch by placing different apertures of diaphragms in front of the last prism of the colour-patch apparatus (and thus throwing on the ground glass discs of light of various areas), the truth of the results was readily verified. The two sets of measures, one made in this way

and the other as just described, gave identical results within the limits of the errors necessarily due to observation.

The method adopted gave the extinction of light on the whole retina, for not only was the central part used, but the extinction was carried so far that it was complete for every part of the eye. As there is a considerable absorption in the yellow spot this is necessary, but the absorption exercised in this part of the eye, which occupies from 4° to 6° angular aperture, can be fairly measured if only the light on a small area be extinguished and this part of the retina be alone used. A very simple way of seeing the absorption of the yellow spot is to form a feeble spectrum some 3 inches long on a ground-glass screen. If the eye looks at the green, a dark band ex-

Table I.

No. 1.

Scale No.	Sector aperture.	Sector aperture reduced.
55·2	180	180
5·3	„	„
54·0	90	90
9·3	„	„
53·2	60	60
10·6	„	„
52·3	45	45
13·3	„	„
51·3	32	32
15·9	„	„
50·5	25	25
16·3	„	„
50·0	22·5	22·5
17·3	„	„
48·4	15	15
19·3	„	„
45·4	11	11
26·3	„	„

D light had to be reduced to 0·17789 its luminosity to equal the light from an amyl lamp at 48 cm. from the ground glass.

No. 2.

Scale No.	Sector aperture.	Sector aperture reduced.
57·3	180	456
2·1	„	„
55·9	90	228
4·3	„	„
54·1	38	97
8·3	„	„
53·1	20	51
12·3	„	„

Luminosity of patch on No. 2 = 2·56 that of No. 1.

No. 3.

Scale No.	Sector aperture.	Sector aperture reduced.
60·8	180	2700
..	..	..
59·4	90	1350
58·3	45	675
56·9	22·5	337
53·4	5	75

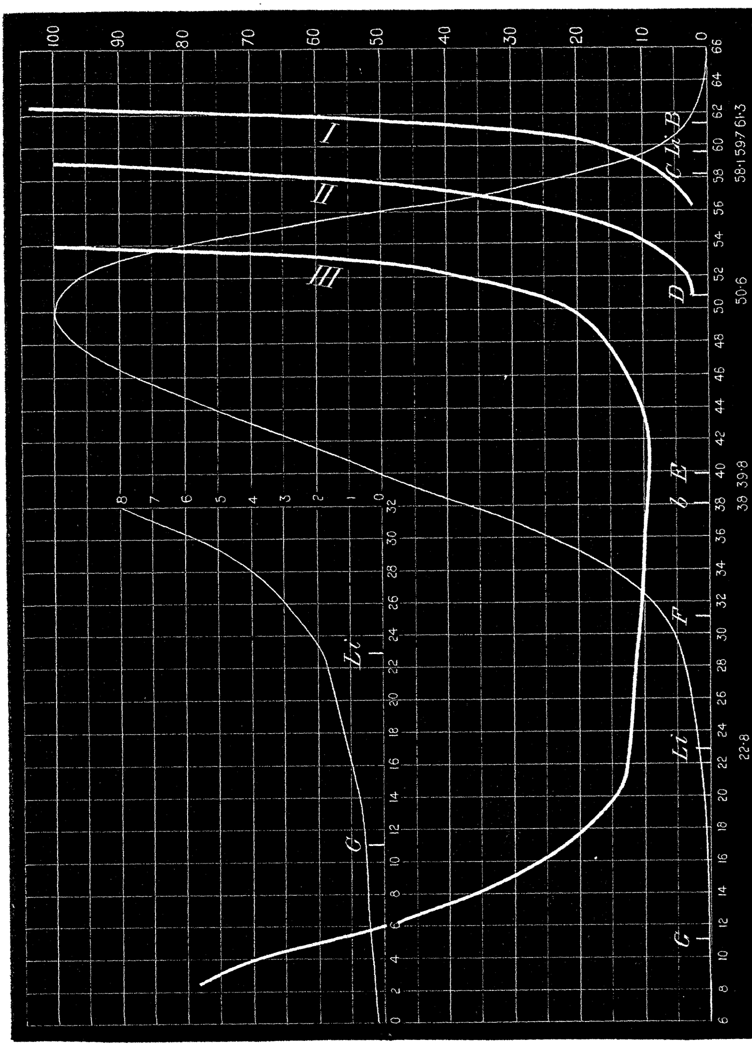
Luminosity of patch No. 3 = 15 that of No. 1.

Table I—*continued.*

No. 4.			No. 5.		
Scale No.	Sector aperture.	Sector aperture reduced.	Scale No.	Sector aperture.	Sector aperture reduced.
52 ·3	180	45	61 ·9	180	6000
14 ·3	”	”	60 ·9	90	3000
			60 ·2	60	2000
49 ·8	90	22 ·5	59 ·0	30	1000
17 ·3	”	”	57 ·6	15	500
			56 ·5	9	300
44 ·3	45	11 ·25			
26 ·3	”	”			
43 ·3	40	10			
35 ·3	”	”			
25 ·3	45	11 ·25			
30 ·3	43	10 ·75			
34 ·3	40	10			
38 ·3	37	9 ·2			
Luminosity of patch in No. 4 = 0 ·25 that of No. 1.			Luminosity of patch in No. 5 = 22 ·2 times that of No. 1. A measure showed that 63 required double the aperture of 62 to be extinguished.		

tending to the blue will be seen, but if the eye be turned towards the red end or violet, the green is seen outside the central spot and the colour reappears. I propose to return to this in a fuller discussion of the subject.

The first table shows the actual observations in the spectrum.



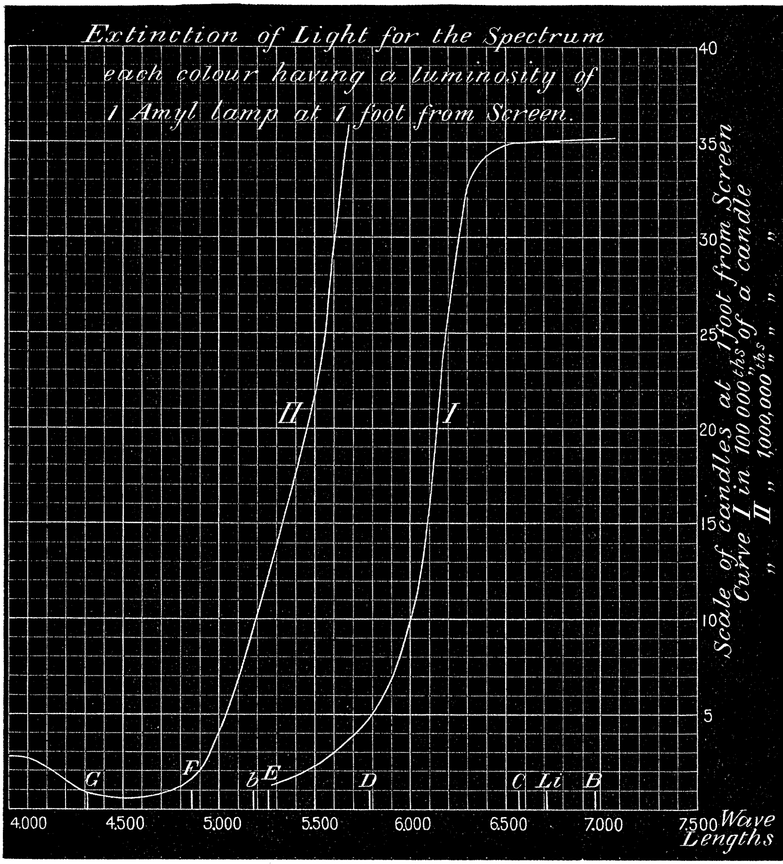
The ordinates of curve II are 10 times that of I, and of curve III 100 times that of I.

The second table attached shows the extinction of light of a luminosity of one amyl lamp placed at a foot from the screen. It

Table II.

Extinction of Rays of Equal Luminosity, the Luminosity being 1 Amyl Lamp at 1 foot from a Screen.

Scale No.	λ.	Reading.	Luminosity of rays.	Extinction of equal luminosities.	$\frac{1}{100000}$ of an amyl lamp 1 ft. off screen.
63	7082	13,000	1	13,000	36·11
62	6957	6,400	2	12,800	35·5
61	6239	3,100	4	12,400	34·4
60	6728	1,800	7	12,600	35·0
59	6621	1,000	12·5	12,500	34·7
58	6520	600	21	12,600	35·0
57	6423	380	33	12,540	34·8
56	6330	240	50	12,000	33·3
55	6242	160	65	10,400	29·0
54	6152	100	80	8,000	22·2
53	6074	55	90	4,950	13·75
52	5996	38	96	3,640	10·11
51	5919	28	99	2,772	7·70
50	5850	21	100	2,100	5·83
49	5783	17	99	1,682	4·65
48	5720	16	97	1,552	4·31
47	5658	14	92·5	1,294	3·59
46	5596	12·4	87	1,078	2·99
45	5535	11·6	81	906	2·517
44	5481	10·0	75	750	2·083
43	5427	9·8	69	686	1·905
42	5373	9·6	62·5	600	1·666
41	5321	9·6	67	546	1·516
40	5270	9·6	50	480	1·333
38	5172	9·6	36	346	0·911
36	5085	9·8	24	236	0·655
34	5002	10·0	15	150	0·4166
32	4924	10·2	8	82	0·2277
30	4845	11·0	5·5	50	0·1388
28	4776	11·2	4	43·6	0·1166
26	4707	11·6	3	35	0·0972
24	4643	12·0	2·2	26·4	0·0733
22	4578	12·4	1·6	20	0·0555
20	4519	14·0	1·4	18	0·0500
18	4459	18	1·2	21·6	0 0600
16	4404	26	0·9	23·4	0·0650
14	4349	36	0·7	25·2	0·0700
12	4298	50	0·6	30	0·0833
10	4247	70	0·55	36·4	0·1011
8	4197	104	0·5	52	0·1444
6	4151	160	0·4	64	0·1777
4	4105	240	0·35	84	0·2333
2	4058	350	0·3	105	0·2916
0	4010				



will be seen that the extinction of the red rays is effected when they are reduced to about 36/100,000 of this standard, whilst the rays near F require a reduction of 5/10,000,000, that is, the sensitiveness of the eye is 700 times greater for the latter colour than the former, and this has a bearing on the extinction of white light of different qualities.

It is worthy of remark that the reduction of the rays from about C to the visible limit of the red necessary to cause extinction from the standard luminosity is practically the same, and points to the fact that this part of the spectrum is probably monochromatic; if admixture of any other colour sensation were present, the curve would rise or fall instead of remaining horizontal. The same apparently applies to the violet end of the spectrum, though, owing to the small luminosity, exact measures of it are less certain. The experiments show that the rays having the wave-length of about λ 4770 are the last perceived. The shift in the position of maximum resistance to

about λ 4510, as shown in Table II, is due to the fact that equal luminosities of each colour have been considered as being reduced.

Some interesting experiments were carried out by placing slits in different parts of the spectrum, and forming a mixture of light on the ground glass of the apparatus. An intense D light mixed with a faint light near F formed a colour patch, and this mixed light was extinguished and found to require 9° of aperture of the sector. The D light was then shielded and the single ray of blue-green light was extinguished, when it was found that the same aperture was required to extinguish this beam alone. Red and green and various other mixtures were tried, all showing that in the extinction of light the green-blue light was the last visible, and was equivalent to extinguishing that light alone, although it might be mixed with very much brighter light in the red or yellow. In the blue the conditions somewhat change, as will be seen in the diagram, but if slits of equal aperture were used the same results were obtained.

The diagram shows that in the spectroscopy of feeble light the rays in the blue and green are the first to be perceived, and that rays of far greater intensity in the yellow and red may exist without exciting the sense of light. This may account for some of the varied results recorded in eye spectroscopic observations of sources of feeble luminosity, in which the yellow and red lines are absent.

In extinguishing white light, the fact of the total extinction of the blue-green light is of importance.

It is not the *light* at that particular wave-length which disappears last, but some one *sensation* which is principally existent at that point, but which extends over a great portion of the spectrum which has to be extinguished. For instance, in extinguishing the light from the reflected beam of the electric light already alluded to, it was found that the light illuminating the ground glass was 720 times brighter than that reaching the screen. To extinguish 0·014 of the light from an amyl lamp on the ground glass the sector had to be closed to 21, that is the light of one amyl lamp luminosity, falling on the screen at 1 foot distance, had to be reduced to $\frac{14}{1000} \times \frac{1}{720} \times \frac{21}{180}$ or $\frac{1}{441{,}000}$ of the original light. Had the luminosity of the unit of luminosity been due entirely to the colour at λ 4776, it would have had to be reduced to about $\frac{1}{900000}$ of its luminosity before it became invisible. Thus the electric light gives about half the sensation of this light that the monochromatic light of that colour and luminosity would give, and hence we may conclude that about half the luminosity of the white light is due to this sensation, of course distributed unequally through its spectrum. This is a very close approach to the area of the green sensation curve of the spectrum when the luminosity is taken into account.

It would thus appear that by studying the extinction curves it may be possible to approximate to the three positions in the spectrum which the colours giving the nearest approach to the three fundamental sensations on the Young-Helmholtz theory occupy.

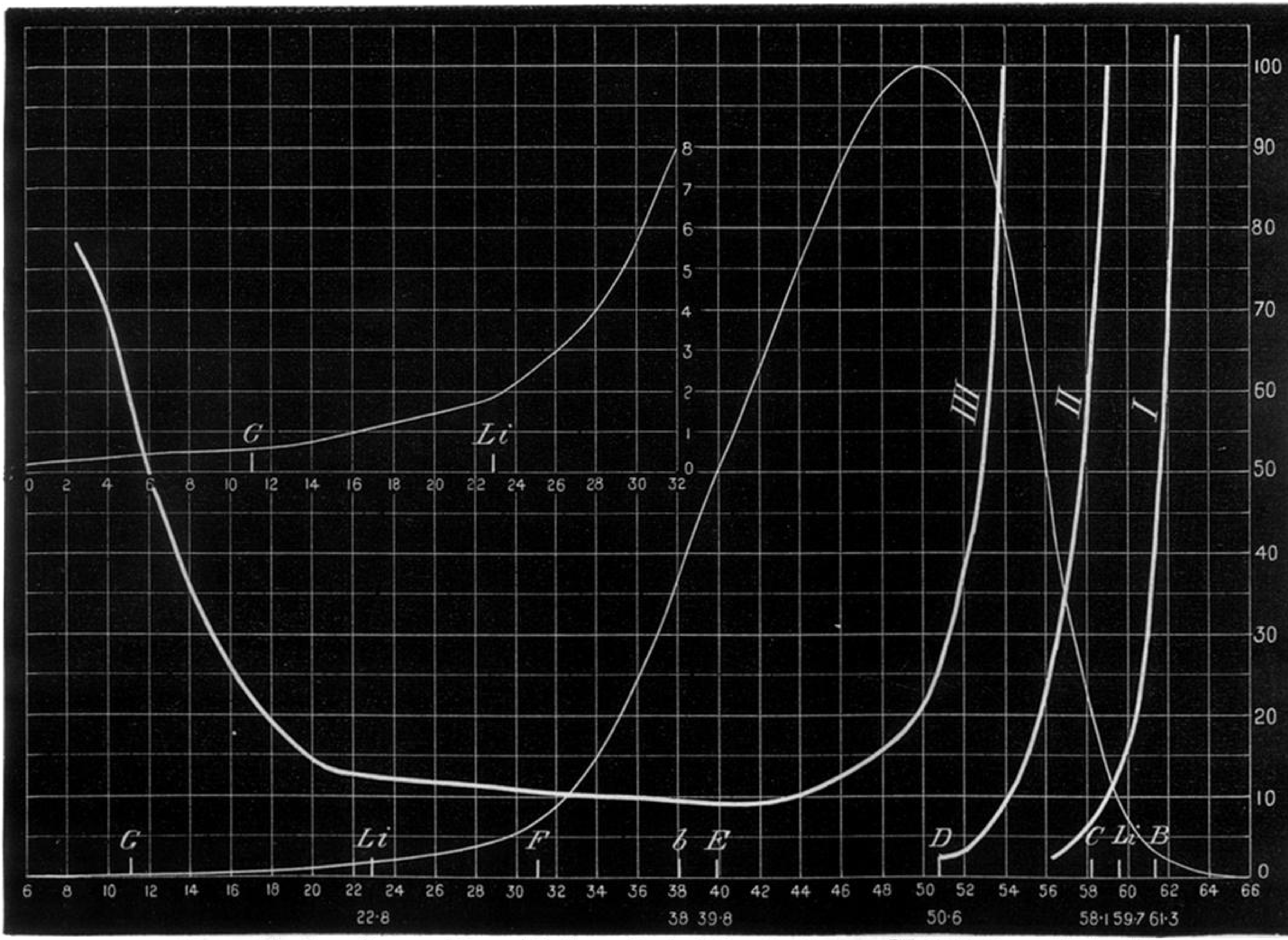
III. "Researches on the Structure, Organisation, and Classification of the Fossil Reptilia. VII. Further Observations on *Pareiasaurus*." By H. G. SEELEY, F.R.S., Professor of Geography in King's College, London. Received May 5, 1891.

(Abstract.)

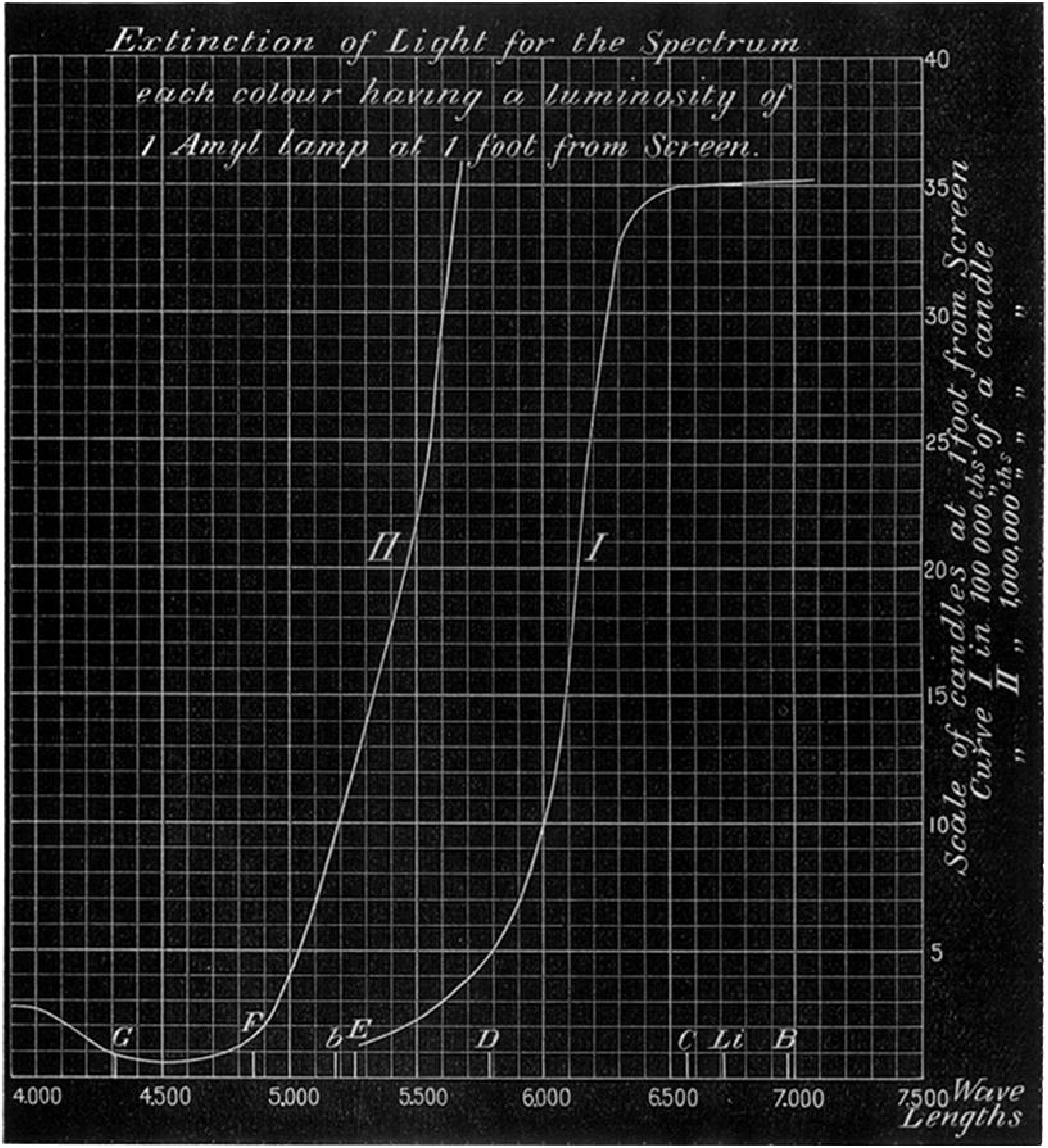
The author distinguishes five zones of life in the Karoo rocks, which are termed, counting from the bottom, Mesosaurian, Pareiasaurian, Dicynodont, Theriodont, and Zanclodont. The Pareiasaurian zone extends between the Prince Albert Road station and the Nieuwveldt range of mountains. He obtained a nearly complete skeleton from Bad, east of Tamboer, a less complete skeleton from Tamboer Fontein, and a portion of jaw from near Klipfontein, on the summit of the Nieuwveldt range. These materials show almost every part of the skeleton except some details of the carpus and tarsus, and the number of digits.

The skull shows in both specimens the structure of the palate, which was closed in the median line, and almost covered with teeth, which extend in four principal longitudinal rows on the vomera and pterygoids. The teeth are slender, cylindrical, and recurved. There are two oblique rows, half as long as the others, on the palatines. They converge backward. Other teeth occur in rows behind these, and in front of them. The posterior nares open behind the pterygoids on the basi-sphenoid. The pterygoid bones diverge backwards to meet the quadrate bones, which are wedged in between them and the bones of the cheek. On the outer border of the side of the quadrate is a perforation like that figured 'Phil. Trans.,' B, 1889, Pl. 10, fig. 4, only smaller. The brain case has the same sort of relation to the roof bones of the skull, as in marine Chelonia. The brain case is depressed behind. The occipital condyle appears to be formed by the basi-occipital in its lower half, and by the ex-occipitals in its upper half. It is concave, and was margined below by a semicircular intercentral bone. A similar intercentral ossification occurs behind it, below the atlas. The surface of the skull has no opening except the nares, orbits, and the large parietal foramen. Its posterior border is concavely notched. The surface shows the same pitted and channeled ornament as in the specimen already described.

The vertebral column is complete with the exception of a few small terminal vertebræ of the tail. No neural arch has been found to the



The ordinates of curve II are 10 times that of I, and of curve III 100 times that of I.


Extinction of Light for the Spectrum
each colour having a luminosity of
1 Amyl lamp at 1 foot from Screen.
40
35
30
25
20
15
10
5
II
I
G
F
b
E
D
C
Li
B
4.000
4.500
5.000
5.500
6.000
6.500
7.000
7.500
Wave Lengths
Scale of candles at 1 foot from Screen
Curve I in 100 000ths of a candle
" II " 1,000,000ths " " "